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Commercial FURFURAL

Its Properties and Uses

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See p. 15.

By Carl S. Miner, John P. Trickey
and Harold J. Brownlee

The Miner Laboratories
9 South Clinton Street, Chicago, Ill.

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Commercial Furfural—Its Properties and Uses

By Carl S. Miner, John P. Trickey and Harold J. Brownlee
The Miner Laboratories, Chicago, Ill.

A Laboratory Curiosity Which Has Lately Become an Important Industrial Aldehyde—Its Occurrence, Manufacture and Properties—Its General Uses—Complete Bibliography

FURFURAL occupies an anomalous position in the realm of chemistry. It was first prepared nearly a hundred years ago and for forty years it has been utilized in a standard and widely used analytical procedure. Yet furfural itself has remained until very recently a chemical curiosity, its chemical properties and even its very appearance practically unknown even to many who have frequently utilized its services in the determination of pentoses and pentosans. A considerable number of years ago, the senior author of this paper had occasion to make several hundred pentose determinations within a few months. Yet despite the fact that in each of these determinations he made furfural by boiling the carbohydrates with acid, distilled that furfural and precipitated it with phenylhydrazin, not once did he see any furfural, since, because of the solubility of furfural in water, no separation of it occurs during the distillation process. The general lack of knowledge of or interest in furfural on the part of the chemical profession becomes the more comprehensible when we realize that it has never been quoted at less than $6.50 per lb. until very recently. Such a price has not encouraged laboratory experimentation nor any important commercial utilization.

Very recently the processes for manufacturing it have been developed to a point where it now sells for substantially less than benzaldehyde and current developments are such that one may confidently predict an ultimate price materially below that at which formaldehyde is now sold. Since it bids fair eventually to become the cheapest aldehydic body commercially available, it has seemed expedient at this time to present a summary of the present state of knowledge of furfural together with the bibliography of the subject which we have thus far compiled. Our own difficulty

in finding information to aid us in our investigation of possible uses for the compound leads us to hope that the publication of this information may be helpful to the workers in this field during the formative period of what seems likely to become an important branch of American chemical industry.

Occurrence and Preparation

Furfural was first obtained by Dobereiner (1)* in 1830 while preparing formic acid by the action of sulphuric acid and manganese dioxide on sugar. During the distillation he noticed that the distillate came over milky and on standing, a yellow "oil" separated out. He succeeded in obtaining only a small amount, not enough to make any extensive investigation of its nature. The "oil" was described as having an odor similar to a mixture of oil of bitter almonds and oil of cinnamon and was given the name "artificial oil of ants." A short time later Emmet noticed that an "oil" was obtained when formic acid was prepared from rye or corn by treating with sulphuric acid.

Stenhouse (2, 6) in 1840 was the first to prepare any quantity of this "oil." He used Emmet's process for preparation of formic acid, using oatmeal and sawdust as the material from which to make the "oil." He succeeded in obtaining a yield of an ounce from twelve pounds of meal. The composition of the "oil" was determined and formula of $C_5H_4O_2$ given to the compound. This formula has been shown by subsequent investigation to be correct. The effect of treating it with acids and alkalis was studied, and its boiling point, specific gravity and solubilities in water and alcohol determined. Comparison of these constants with those determined more recently indicate that Stenhouse was working with a very impure product.

Fownes (3) in 1845 was the next to work on an "oil" obtained by distillation of bran with sulphuric acid. He found this to be identical with the "oil" studied by Stenhouse and suggested the name furfurol (furfur-bran, oleum-oil). Ultimately, when the aldehyde nature of the compound was established, it became known as furfuraldehyde, which is now ordinarily abbreviated to furfural. He also prepared the ammonia compound to which he gave the name furfurol amide

*Numbers in parentheses refer to the bibliography which will be found on the pages beginning with page 16.

(now furfuramide). The formulas for the two compounds were determined as $C_{15}H_6O_6$ for furfurol and $C_{15}H_6NO_5$ for furfurol amide. He also prepared a compound from the amide which he named furfurin and having the formula $C_{30}H_{12}N_2O_6$. Cahours (7) also obtained furfural from wheat by sulphuric acid distillation and prepared the amide and furfurin. Stenhouse in 1850 (6) prepared "oils" from various vegetable sources and found that these "oils" were similar, but from some classes of vegetable growth, especially seaweeds, there was an "oil" obtained which he claimed was an isomer of furfural and to which he gave the name fucusol. This compound gave an ammonia compound, fucuscamide, and from this by action of dilute potassium hydroxide fucusin could be prepared. In later papers further study is made of fucusol and an acid is prepared analogous to the acid obtained by oxidation of furfural, pyromucic acid, to which he gave the name β-pyromucic acid.

Maquenne (15) and Tollens proved the fucusol of Stenhouse to be a mixture of furfural and methyl furfural. This is the first record of differentiation between furfural and methyl furfural, the product formed by hydrolysis of methyl pentosans.

Many others worked on furfural preparing it from a wide variety of materials such as cane sugar (4), wood (10), glucose (22), and albumen (21), and eventually it was found that pentoses and pentosans were the substances ordinarily yielding furfural, although in a few cases such as glucose, cane sugar, etc., furfural is produced in very small quantities from carbohydrates other than pentoses.

Neff, in his investigations of the actions of various oxidizing agents on glucose, has isolated a series of acids containing 1, 2, 3, 4, 5 and 6 carbon atoms. This reaction is not progressive, the acids being formed simultaneously. This phenomenon explains satisfactorily the fact that small amounts of furfural are produced by action of sulphuric acid on the hexoses. Sulphuric acid, being an oxidizing agent, first oxidizes the sugar to a five-carbon compound and from this the furfural is probably derived.

It has been shown that some proteins, especially the nucleo proteins, contain pentose groups, a fact which offers an explanation of the reported production of furfural from "albumen."

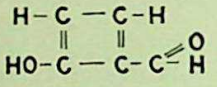
It was also found that furfural may be prepared by

distillation of pentosans with concentrated solutions of zinc chloride, calcium chloride (5) and other acid salts, as well as by dry distillation. Furfural has been found in commercial fusel oil (109), glacial acetic acid (9), and sulphite-waste-liquors (19). In the case of fusel oil, the furfural was not the product of normal fermentation, but was found to be due to the action of certain acids on solids of the mash during distillation (17).

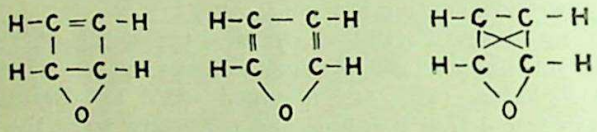
It may be noted that all the products in question where furfural occurs as an impurity have been subjected during the process of manufacture to conditions where a mixture of carbohydrates and acid may have been acted upon by heat.

Structure of Furfural

Limpricht (29) in 1869, by studying the actions of the furfural group with bromine, chlorine, etc., proposes the formula



Baeyer (30) proposes the formulas

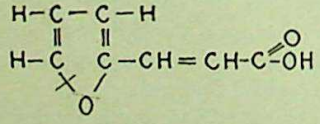


and from the results of his work considers formula 1 as representing the formula of the furfurane group.

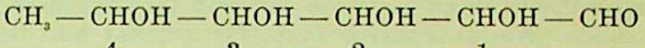
Pawlinoff (31) by means of the zinc ethyl reactions established the non-presence of any hydroxide group and favors formula 2 of Baeyer. Markwald prepared a keto acid from furfuracrylic acid having the formula

$$HOOC - CH_2 - CH_2 - CO - CH_2 - CH_2 - COOH$$

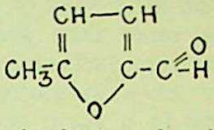
proving the position of the ketone group and concluded that the structure of the furfuracrylic acid is



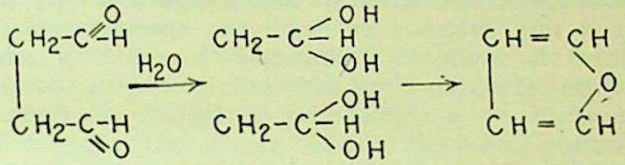
The break in the ring comes at the place indicated, in the forming of the keto acid. Tollens (35) and Maquenne (15) determined the structure of methyl furfural by its derivation for isodulcite



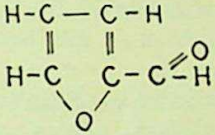
an anhydride being formed by the dehydration of the two alcoholic groups 1 and 4 to give the formula



Harris synthesizes furfurane by heating succinic-dialdehyde with water as follows:



From this evidence the formula for furfural has been accepted as



Manufacture

Until very recently furfural has not been manufactured in commercial quantities and although a number of methods of producing it have been proposed at various times, so far as we are able to learn very few of these have ever been practiced. In the case of those who have actually produced furfural on a commercial scale, very little publicity has been given to the methods used. We can only judge from such uncertain data as the patents issued to them or their published work. On this basis there is some reason to believe that much of the furfural which has been imported has been made from kapok waste by a method which, in a general way, approximates the laboratory procedure for the determination of pentosans, which consists in boiling the pentose-bearing material with 12 per cent hydrochloric acid and distilling. In this country, the excellent research conducted by the Bureau of Chemistry has developed a method not yet utilized commercially so far as we are aware, in which corn cobs or similar materials are treated in a stationary digester at

comparatively high pressure without the introduction of acid. We understand that this process has been operated successfully on a semi-commercial scale in connection with the bureau's experimental work.

Our own investigations in this field have led us to select oat hulls as the most readily available raw material for the process, since they are produced continuously throughout the year in large quantities (as much as 200 tons a day at a single plant) by factories centrally located and in a form convenient for treatment. We have developed a simple and effective procedure in which the hulls are subjected to the action of steam and acid in large rotary digesters. By this method very satisfactory yields are obtained and the furfural is produced admixed with relatively small quantities of water. This process is now being operated successfully in a commercial production of furfural amounting to several tons per month, which production will be very greatly increased in the near future.

Since the theoretical yield of furfural from oat hulls is in the vicinity of 20 per cent and the annual production of oat hulls in the United States 220,000 tons, the possibilities of production of furfural from this source alone are enormous.

Chemistry of Furfural

In the following, a rather brief survey of the work done on the compounds of furfural has been made. Our endeavor has been to present a few of the typical examples showing in a general way the types of reactions into which furfural enters and the chemical nature of the compound itself. In the bibliography appended, a much larger number of references will be found than are cited in the body of the paper.

But very little work has been done on the physical properties of furfural. Its boiling point has been determined by a number of workers with varying degrees of accuracy. Probably the most exact results are those of Mains, of the Bureau of Chemistry, recently published in *Chemical and Metallurgical Engineering* (260). Working on a highly purified product, he found the boiling point as 161.7 deg. C. at 760 mm. Its specific gravity was also determined by Mains as $1.1598^{\frac{20}{4,\ Vac}}$ and $1.1545^{\frac{25}{4,\ Vac.}}$. Its solubility in water and the composition density tables at 20 and 25 deg. C. he determined up to the saturation concentration. The solubility data are reproduced in Table I.

TABLE I—OBSERVED DATA ON MUTUAL SOLUBILITY OF FURFURAL AND WATER

Water Layer		Furfural Layer	
Temperature, Deg. C.	Per Cent Furfural by Weight	Per Cent, Deg. C.	Per Cent Furfural by Weight
16	8.12	8	96.5
17.0	8.18	26.6	94.6
27	8.72	37	93.3
27.2	8.72	44	92.8
27.5	8.68	65	90.9
44	9.80	70	90.3
61	11.9	84	88.0
66	12.5	96	84.5
92	17.0	....	....

Bruhl (80) determined its refractive index with the following results:

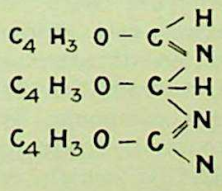
$$\mu_a = 1.51862$$
$$\mu_D = 1.52608$$
$$\mu_\beta = 1.54566$$
$$\mu_\gamma = 1.56484$$

Sir W. Ramsay determined its heat of formation as 5,985 cal. The flash point of furfural is 55 to 57 deg. C. Other physical constants of furfural are now the subject of investigation by several workers whose results will be published shortly.

In general it resembles in its reactions benzaldehyde on one hand and formaldehyde on the other. It differs from both of them in being a liquid of very high boiling point and wide range of solvent power.

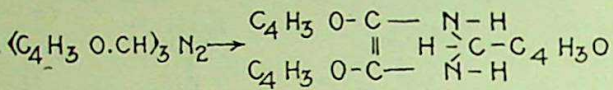
It was early discovered that furfural had many chemical characteristics in common with benzaldehyde, which led to a rather extensive study of its reactions with various aliphatic and aromatic compounds as well as the study of the reactions of furfural with ammonia, hydroxylamine, etc.

Among the earliest compounds prepared was furfuramide. Stenhouse, Maquenne, Fownes and others prepared the compound, but its structure was first determined by R. Schiff to be



As the corresponding benzaldehyde ammonia compound is converted by treatment with dilute alkali solution into benzin, Bahrmann, Schiff and Cahours pre-

pared furfurin by similar treatment. Bertaginini (129) prepared furfurin by simply heating furfuramide at 110 to 120 deg. C. for about an hour.



This compound is much more basic than furfuramide, forming well-defined salts with acids and being alkaline to indicators. Ramsay (89) established that furfurin was a secondary base with two replaceable hydrogens.

By the same method that benzaldehyde, by treatment with alcoholic KOH, is converted into benzylalcohol and benzoic acid, Schiff (97) and Limpricht (99) prepared pyromucic acid and furfuralcohol.

$$2C_5H_4O_2 + KOH \rightarrow C_5H_6O_2 + C_4H_3O.COOK$$

Pyromucic acid was also prepared by oxidation of furfural with silver oxide (96). Furfuralcohol prepared by reduction of furfural with sodium amalgam (95)

$$C_4H_3O.CHO \rightarrow C_4H_3O.CH_2OH$$

Furfurnitrile is prepared by action of PCl_5 on pyromucicamide (94)

$$C_4H_3O.CONH_2 + PCl_5 \rightarrow C_4H_3O.CN + POCl_3 + 2HCl$$

The nitrile by reduction with zinc and H_2SO_4 to furfurylamine (94)

$$C_4H_3O.CN + 2H_2 \rightarrow C_4H_3O.CH_2.NH_2$$

E. Fischer (88) prepared furoin by action of KCN in alcoholic solution on furfural.

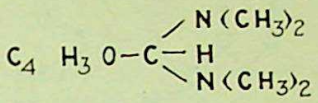
$$2C_4H_3O.CHO \rightarrow C_4H_3O.CO.CH(OH).C_4H_3O$$

This compound oxidized gives furil, $C_4H_3O.CO.CO.C_4H_3O$. Fischer also prepared mixed compounds such as benzfuroin, $C_4H_3O.CO.CH(OH).C_6H_5$, etc. Furfural forms condensation products with urea and related compounds.

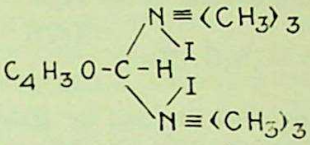
The reactions of furfural with aliphatic compounds have been rather extensively studied. Priebs (237) studied the condensation of nitromethane in alkaline solutions preparing furfurnitroethylene, $C_4H_3O.CH:CHNO_2$, and from this compound by ordinary nitrating methods prepared nitrofurfurnitroethylene, $C_4H_2O(NO_2)(CH:CHNO_2)$, which on oxidation gave nitromucic acid, $C_4H_2O(NO_2)(COOH)$.

Litterscheid (236) prepared furfuryliden-methylamine, $C_4H_3O.CH:NCH_3$, by the action of furfural on

methylamine, also the compound furfurylidentetramethyldiamine



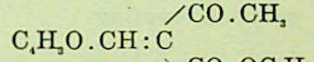
Both of these compounds form salts with acids and addition products with alkylhalides such as



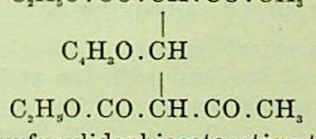
Claisen (233), Mehne (232) and Schmidt (231), prepared condensation products of furfural with acetone and acetaldehyde such as: Furfuracrolein, $C_4H_3O.CH:CH.CHO$; furfuralacetone, $C_4H_3O.CH:CH.CO.CH_3$; difurfuralacetone, $C_4H_3O.CH:CH.CO.CH:CH.C_4H_3O$; as well as mixed compounds such as benzal-furfural-acetone, $C_4H_3O.CH:CH.CO.CH:CH.C_6H_5$

Claisen (226), Hill (228), and Markwald (227) condensed furfural with acetic acid forming furfuracrylic acid, $C_4H_3O.CH:CH.COOH$, and studied the halogen compounds of the acid.

Claisen (211), Knoevenagel (224) and Sandelin (207) condensed furfural with acetaceticester forming

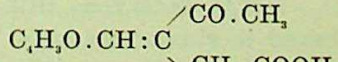


Furfuralacetaceticester



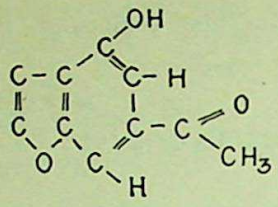
Furfurylidenbiacetaceticester

By condensation of furfural with levulic acid, Ludwig (206), Kehrer (205) and Erdman (86) prepared



β-furfuryl-levulic acid

which on distillation in a current of H_2 or CO_2 condenses forming



Acetooxycumaron.

Succinic and malonic (154) acids condense with furfural forming compounds of the type

$$C_4H_3O.CH:C\begin{matrix}/COOH\\ \backslash COOH\end{matrix}$$

Similar reactions were studied by Rohmer (214), Volander (215), Tonnies (213) and others.

The action of phenylhydrazine, hydroxylamine, barbituric acid and phloroglucinol was studied in relation to the quantitative determinations of furfural, pentoses and pentosans. Tollens, Cross and Bevan, and Unger and Jaeger did by far the most work on this subject.

Furfural condenses with acetophenone (165) to form furfural-acetophenone, $C_4H_3O.CH:CH.CO.C_6H_5$, and furfuryl-di-acetophenone

$$C_4H_3O.CH\begin{matrix}/CH_2.CO.C_6H_5\\ \backslash CH_2.CO.C_6H_5\end{matrix}$$

Benzylcyanide (167) condenses with furfural to form α-phenylfurfuracrylicnitrile, $C_4H_3O.CH:C(C_6H_5)(CN)$, which is easily reduced forming

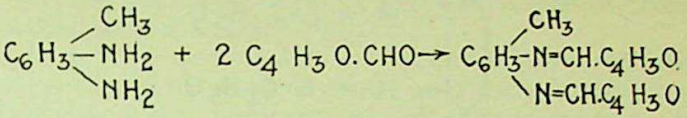
$$C_4H_3O.CH_2.\overset{\displaystyle C_6H_5}{\overset{/}{C}}H.CH_2.NH_2$$

α - furfur - β - phenyl-propyl-amine

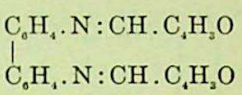
By far the greatest amount of work has been done on the reaction of furfural with the amines and related compounds because of the possibility of developing dyes. As early as 1870, Stenhouse (203) prepared the compound of furfural with aniline and various acids, finding that additional products were formed,

$$C_5H_4O_2.2C_6H_5NH_2.HCl.$$

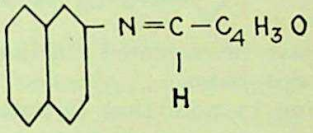
Toluidine behaved in similar manner. H. Schiff (175) supports Stenhouse's reaction and further shows that diphenylamine and *m*-nitraniline react in similar way, forming addition products. However, monomethyl-diamino-benzene follows the regular aldehyde reaction.



Benzidene reacts in similar manner, condensation taking place with both amino groups forming

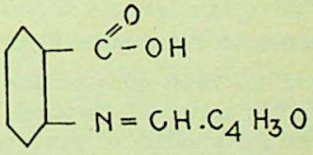


G. de Chalmot (168), however, claims that the reaction of furfural with aniline is a true condensation, the reaction taking place according to the aldehyde-amine condensation reaction. Schiff (170) also studied the action of furfural on various other amines, diamines, tri-amines, as well as acid amines, forming compounds such as



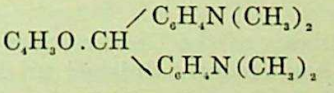
β-furfuronaphtylamine

and

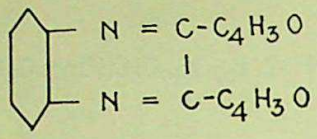


o-furfuramidobenzoic acid

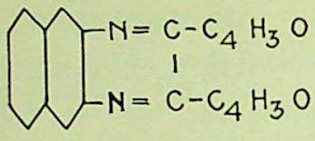
O. Fischer (180) and Schiff (177) studied the analogous reaction to the preparation of malachite green from benzaldehyde and dimethyl aniline forming tetramethyl-diamino-diphenyl-furyl-methane



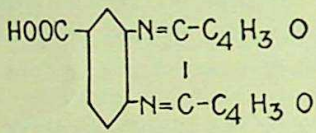
This compound on oxidation forms a dye analogous to malachite green. This reaction has recently been more thoroughly investigated by Renshaw and Naylor and a very satisfactory dyestuff obtained. Fischer (181) also studied the reaction of furoin on o-phenyldiamine and α-β-naphthylendiamine forming



and



Zehra (182) prepared a similar compound from 1:2 diamino 4 benzoic acid



Many others have investigated reactions of this type, forming many color bases.

It is interesting to note that in spite of the large amount of work done on the chemistry of furfural that no study has been made of the nature of the chemical reaction taking place in the formation of resinous condensation products.

Physiological Action of Furfural

But little work has been done on the toxicity or the general physiological action of furfural. Jaff and Cohn (118) studied the metabolism of furfural in dogs, rabbits and hens, and isolated from the excreta considerable amounts of pyromucic acid, a compound of pyromucic acid with glycocoll which they called pyromykuric acid, and a substance difficultly soluble in water which proved to be a glyococoll compound with furfuracrylic acid. Mention is made of the toxic effect, but no specific data are given.

Hugh McGuigan, of the University of Illinois, College of Medicine, has recently finished an investigation on the action of furfural on bacteria, yeast, gold fish, frogs, white mice, rabbits, cats and dogs. The results of this investigation will be published shortly in the *Journal of Pharmacology & Experimental Therapeutics*. Dr. McGuigan has kindly communicated to us the results obtained, which briefly are as follows:

1. The phenol coefficient of furfural, measured from its bactericidal action, is 0.26.

2. A 2 per cent solution of furfural entirely inhibits the action of yeast on dextrose. A 1 per cent solution only delays this fermentation. Weaker solutions have no effect.

3. Furfural is about one-half as toxic for gold fish as phenol and about one-third as toxic as formaldehyde for the same animal.

4. Furfural in large doses has a paralytic effect on frogs similar to chloral. There are evidences of stimulation of the central nervous system when smaller doses are used, but this is more marked in cats. Locally it is corrosive and anesthetic.

5. The fatal dose by stomach for rabbits is about 0.8 c.c. per kg. of body weight. The action on white mice is similar to that on rabbits.

6. In the case of cats, 0.12 c.c. is the fatal dose and with dogs the action is similar.

General Uses

Early in the investigation of furfural, its property of discoloration was noted especially when exposed to light, the change taking place more rapidly in the anhydrous material than in the technical, which contains about 4½ per cent water. When technical furfural is distilled at atmospheric pressure to separate impurities, the color change in the purified product is quite rapid, changing in the course of a day from nearly colorless to a deep amber color. However, by using the method as given by R. Adams, this color change is retarded to a considerable extent. This method is briefly as follows: The technical furfural is distilled under diminished pressure (26 to 28 in. of vacuum) using a paraffine bath, the temperature of which is kept below 130 deg. C. At first water and furfural distill and separate in two layers. After about 15 per cent of the initial volume is collected the distillate coming over is pure furfural. The next 65 per cent is then collected as pure material. It should be stored in amber colored bottles.

Those who require a highly purified furfural for experimental work will obtain very satisfactory results by distilling technical furfural in accordance with the above directions just at or near the time it is desired for use.

Resins

Recently there has been an active interest taken in the manufacture of resins from furfural. Quite early in the history of furfural it was noted when working with the pure product or very concentrated solutions that instead of the desired reactions taking place, a tarry mass resulted. Stenhouse, in 1840, and Fownes, in 1845, in their earliest work on furfural, observed the formation of a brown resinous mass when furfural was boiled with alkali or acid. In 1887 L. Claisen attempted to prepare compounds from β-naphthol and furfural, using glacial acetic acid as the solvent and hydrochloric acid as the condensing agent. He obtained no well characterized compounds, obtaining only a brown resinous mass. No particular notice was taken of these products until the production of the phenol-formaldehyde resins became of commercial importance. Meunier (262) prepared a fusible, soluble resin by action of commercial aniline with an equal part of furfural in presence of alkalis. The product was a black resin, soluble in benzene and alcohol, giving a black enamel. Beckman and Dehn (261) made a rather extensive investigation of the condensation products of furfural with the phenols. They reported on the products obtained from 24 different phenolic compounds. They obtained their best results with phenol, raw cresol, guiacol, carvacrol and β-naphthol, using 5 per cent of hydrochloric acid as the condensing agent and equal parts furfural and the phenol.

Their work using basic catalyzers such as sodium carbonate, sodium hydroxide, etc., seemed to show that the reaction as well as the final product was not as desirable as the acid resins. In the experience of the authors this is at variance with the facts, as in our experience the alkali resins are much more easily controlled and the final product much superior to the acid resins. A paper is being prepared covering our work on these resins.

Mains and Phillips (258) prepared a series of resins from furfural with amines. In all cases they were fusible and soluble, the solutions forming excellent enamels.

Quite recently Novotny has patented a process for preparation of phenolfurfural resins using both furfural and furfuramide in its preparation. These are molding resins forming hard, infusible, insoluble products. We are informed that molding resins now are

being successfully prepared on a commercial scale from furfural.

Varnish

Besides the preparation of the fusible, soluble resins which may be used as varnish resins, investigations have been made which seem to show the applicability of furfural either alone or in admixture with oil of turpentine in the preparation of varnishes. Claim is made of a much lower acidity than in the common methods of varnish manufacture.

Rubber

Some work has been done on the use of furfuramide in the rubber industry as a substitute for hexamethylenetetramine. The results of this work show some promise of its adaptability. It has been found to have decided accelerating effects. Further work is being done on this phase of its application.

Dyes

Practically all of the compounds reported on in the section of this paper devoted to the chemistry of furfural which are formed by the action of furfural on aromatic amines are either highly colored compounds or become so by oxidation. Many of these have decided staining or dyeing properties and in the light of recent investigations furfural gives promise of becoming of importance in the preparation of commercial dyestuffs.

Anesthetics

Dr. Gilman, at the Birmingham meeting of the American Chemical Society, reported on the preparation of an anesthetic from furfural. This opens up an entirely new field in the application of furfural.

Antiseptics and Germicides

Furfural has decided antiseptic and germicidal properties, as is brought out by the work of McGuigan. The authors of this paper studied the effect of furfural on the keeping qualities of bacteria infected glue. They found that glue that "went bad" in 18 to 24 hours after placing in solution would keep for several days when the solution was made in a 1:500 furfural:water solution, and that the solutions would keep for several weeks when made in a 1:250 furfural:water solution.

Solvent

The authors have under way an investigation of the solvent action of furfural. Among the interesting data developed to date are the facts: that furfural is an excellent solvent for both nitrocellulose and the hydrated cellulose acetates; that while linseed oil is very slightly soluble in furfural, chinawood oil is miscible in all proportions; that stearic acid is quite soluble in hot furfural, but is only soluble to about 1 part in 50 at 25 deg. C., while oleic acid is readily soluble at 25 deg. C.

Larger production and increased efficiency of manufacturing process will make possible the reduction in the price of furfural to a point where it can compete on a parity, or better, with formaldehyde and the high boiling point solvents. In view of the many possibilities of commercial utilization already indicated, it seems highly probable a vastly greater number of profitable methods for its use will be developed. Since it can be made from any of the pentosan-bearing roughages now either wasted or sold at extremely low price, it seems reasonable to predict that a considerable percentage of those millions of tons of what is now virtually waste material will ultimately form the basis of a new industry of enormous proportions.

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